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Estimating bounds on the economy-wide effects of the CEF policy scenarios

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Abstract

The *Scenarios for a Clean Energy Future* study relied primarily on "bottom-up" technology-based methods to estimate costs associated with its scenarios. These methods, however, do not allow for calculation of economy-wide or general equilibrium effects of the policies considered. We propose and apply a means of combining the bottom-up estimates with estimates of the costs associated with a carbon charge obtained from computable general equilibrium models. Our approach is based on the concept of production inefficiency: the economy lies within its production frontier with respect to the provision of energy services. The CEF technology policies are interpreted as moving the economy toward its frontier as well as moving the frontier outward, while the carbon charge induces a substitution effect along the frontier. This perspective allows a synthesis of the two sets of calculations.

Keywords: Energy efficiency; Production possibilities frontier; General equilibrium and macroeconomic effects

1. Introduction and overview

In September 1997, five of the US Department of Energy's National Laboratories issued a report, *Scenarios of US Carbon Reductions* (Interlaboratory Working Group, 1997), that assessed the potential for and costs of reducing carbon emissions in the United States. This report, known colloquially as the "Five Lab" study, was influential in the policy discussions that took place prior to Kyoto, and was widely cited in the year following its release. The study concluded that significant carbon reductions were possible at a modest cost or even a net savings to the economy.

The Five Lab study was, however, criticized—particularly by some economists involved in energy and carbon policy analysis—on the grounds that it did not:

- enumerate the specific policies and programs that would be required to promote implementation of the energy efficient and low carbon technologies needed to achieve large carbon reductions;
- explicitly incorporate fuel price feedbacks into its assessment of the societal costs and benefits, because it relied on independent sectoral analyses, not on an integrating modeling framework; and
- explicitly treat the macroeconomic impacts of a carbon permit trading system resulting in a permit price of $50/ton of carbon.

The *Scenarios for a Clean Energy Future* (CEF) study was initiated by the Department of Energy, Office of Energy Efficiency and Renewable Energy, in consultation with the national laboratories, to address these criticisms in a technology-oriented assessment of potential carbon abatement policies. First, the CEF study explicitly identifies policy pathways for each sector, describing and documenting estimates of the costs and effectiveness of particular policies and programs. Second, while based on detailed sectoral analysis (like the Five Lab study), the CEF applies Lawrence Berkeley Laboratory's version of the US Energy Information Administration's National Energy Modeling system (LBNL-NEMS) as an integrating framework.

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The third area of criticism—macroeconomic impacts—is the subject of this paper. Specifically, we propose a framework for interpreting the macroeconomic effects that might occur under the types of scenarios analyzed in the CEF, and use this framework to obtain a range of estimates of these effects associated with the Moderate and Advanced scenarios as described in the CEF study.

It should be noted that the term "macroeconomic" is used in several, not always consistent, ways in this context. Beyond meaning "economy-wide" in general, "macroeconomic" has several competing connotations in contemporary economics. First, there is the Keynesian idea of short-run, disequilibrium dynamics, with particular emphasis on involuntary unemployment. Examples of this approach are the Data Resources Inc. and WEFA models. Second is the approach that treats the entire economy as the sum of its *microeconomic* components, assuming market equilibrium and rational consumers and firms. This paradigm underlies the "computable general equilibrium" (CGE) models such as those of Jorgenson and Wilcoxen (1993), Goulder (1995), and Edmonds et al. (1992).

In this paper our primary framework and calculations focus on this second meaning of the term "macroeconomic", and the associated CGE models, because these are generally regarded as more appropriate than Keynesian models for analysis on the time scales of the CEF, through 2010 or 2020. We will, however, briefly discuss the application of one Keynesian-style macroeconomic model—that of Data Resources Inc. (hereafter, "DRI")—to the analysis of the shorter-horizon effects of certain policies to reduce carbon emissions.

This paper, which is adapted from Appendix E-4 of the CEF, is a contribution to the long-standing "top-down/bottom-up" debate on economic vs. technology-based assessments of markets for energy efficiency and its implications for carbon policy. This debate has its origins in the fact that the premises of technology-focused analyses such as the CEF regarding consumers' and firms' decision-making on energy efficiency as well as the overall performance of markets for energy efficiency differ substantially from the assumptions embodied within "top-down" models of both the CGE and Keynesian varieties. We do not, however, directly address these premises, which are the subject of a substantial literature.[1] Instead, we propose a framework within which the findings of *both* approaches can be combined.

[1]A comprehensive overview of the debate as of the mid-1990s, presenting both "pro" and "con" positions, is contained in Huntington et al. (1994). In addition, the "bottom-up" case is argued by, among others, DeCanio (1997, 1998, 1999), Howarth and Andersson (1993), Howarth and Sanstad (1995), Krause (1996), and Krause et al. (1993), while expositions of the "top-down" position include Sutherland (1996, 2000), Jaffe and Stavins (1994), Jaffe et al. (1999), and Newell (2000).

We thus begin with a theoretical discussion of the relationship between the CEF approach and the equilibrium concept embodied in the CGE models. Next, we apply this discussion to obtain order-of-magnitude estimates of the combined macroeconomic impacts of the CEF policies and the \$50/ton carbon charge envisioned in the Advanced scenario. These calculations are carried out under conservative assumptions regarding the disposition of the emissions permit revenues. We then go on to review the role of fiscal policy in the modeling of carbon policy. The introduction of carbon taxes or a system of auctioned tradable carbon emissions permits would result in a considerable flow of revenue to the government. This revenue could be returned to the private sector in a number of ways. A large body of literature on the economics of carbon policy has demonstrated that exactly how this revenue is "recycled" to the economy has a substantial impact on the economic effects of abating carbon emissions through the price mechanism. We summarize the basic ideas and findings of this literature and provide examples of the quantitative implications of other assumptions. We go on to briefly discuss shorter-term macroeconomic impacts of carbon charges as these have been estimated using the DRI model, and end with concluding remarks.

2. Combining the technological and general equilibrium perspectives

We begin with a brief exposition of the "textbook" approach to defining economic efficiency that we will apply to the CEF results. In the standard model, a set of economic resources (inputs) makes it possible to produce a set of different combinations of various desirable goods and services (outputs), e.g. guns and butter (see Fig. 1a). The set of all *maximal* such combinations defines the "production possibilities frontier". That is, along this frontier there is a resource constraint, so that increasing one output requires reducing some other output. This resource constraint that prevails at the frontier is the source of *opportunity cost*, the loss in output of one type when another type of output is produced instead.[2] When goods are appropriately priced, an optimal or efficient allocation exists, represented in the figure by the point M; at this point, the

[2]There are many types of constraints that can create opportunity cost. There may be constraints on R&D spending or the attention of decision-makers such that activities to advance technology or promote efficiency in one sector imply that advances or efficiencies are forgone in other sectors.

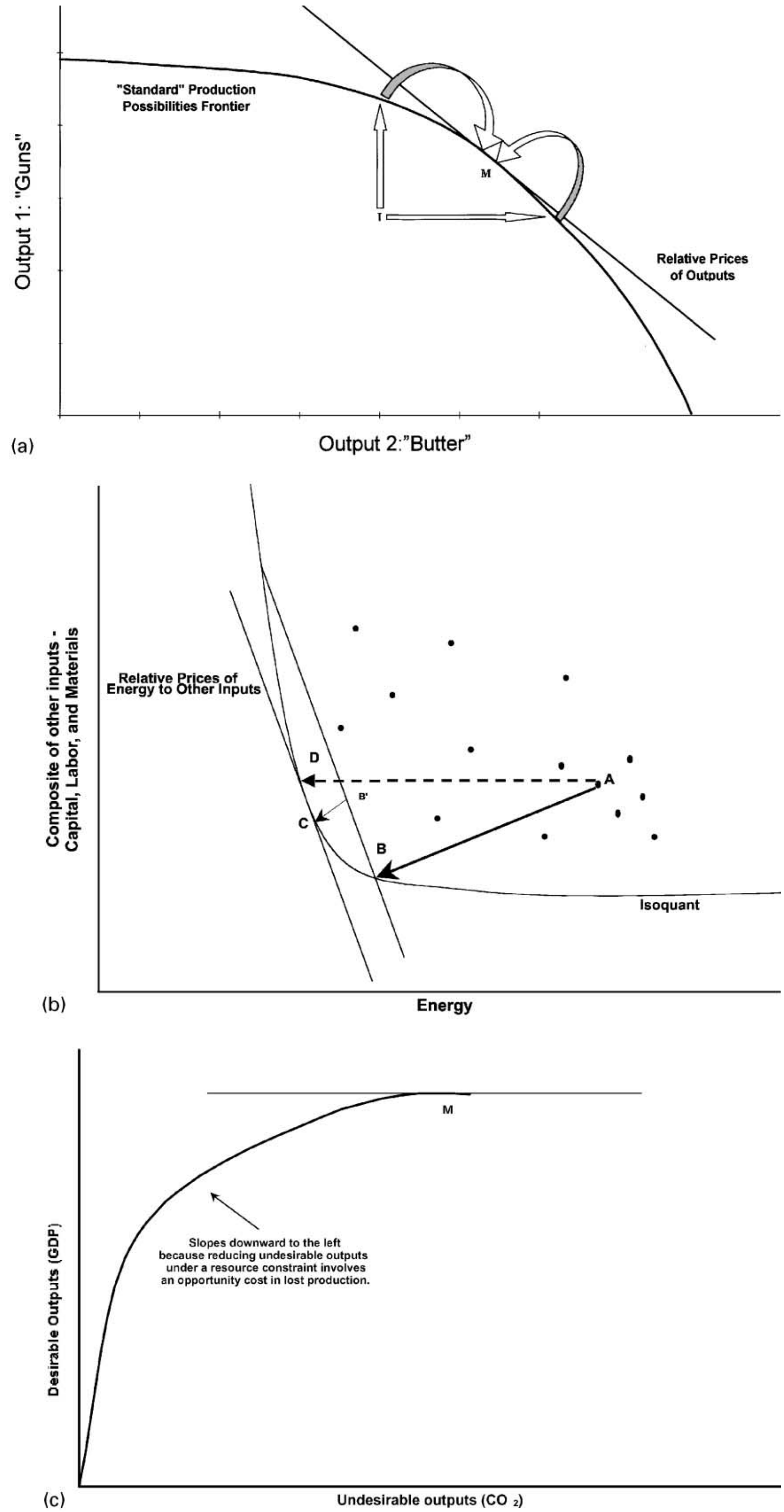

Fig. 1. (a) Standard production possibilities frontier. (b) Standard production (input) frontier with technical and allocative inefficiency. (c) Production possibilities frontier with undesirable outputs.

opportunity cost(s) are equal to the prices of the alternative outputs.[3]

However, if production is inefficient, i.e. interior to the production possibilities frontier as shown by point I, any movement which increases either or both outputs (as shown by the straight arrows or corresponding movement in a direction northeast of point I) results in a Pareto improvement—an increase in one or more types of output without a decrease in any other.[4] This same concept of economic efficiency can also be examined by looking at the "input side", instead of the "output side".[5] In this context, economic efficiency is the optimization of production activities within a well-defined economic sector. To be economically efficient in this sense requires "technical" efficiency, i.e. that inputs be used effectively so that a reduction in any input would lead to a reduction in output. This is illustrated in Fig. 1b. The isoquant shows combinations of inputs that can produce a fixed level of output, y. Starting at the inefficient point A, inputs can all be reduced to reach the technically efficient point B, or only a subset of the inputs can be reduced to reach the technically efficient point D. When production is technically efficient, then economic efficiency further requires that cost be minimized in the traditional sense, as at point C. Costs are understood to be as fully specified as possible, i.e. include transaction costs, etc.

Thus, in this framework, technical efficiency is a necessary but not sufficient condition for economic efficiency. When production is technically efficient, as defined above, then the deviations from cost minimization are called 'allocative inefficiency', because the reallocation of input resources could lower cost while maintaining the same level of production. The arrow between B' and C in Fig. 1b represents the cost reduction possible by changing the input mix in moving from B to C.

To summarize, "an improvement in economic efficiency" can mean one of several things. From the input perspective, it can mean that technical efficiency improves (input use is lower without lowering output), allocative efficiency improves (input mix changes that lower costs), or both. Corresponding concepts exist on the output side (see Fig. 1a) or simultaneously for inputs and outputs (see Färe and Primont, 1995 for underlying theory and examples).

[3] Opportunity costs can also be expressed in terms of input prices under suitable profit-maximizing conditions.

[4] This is similar to the standard gains-from-trade-model, when indifference curves are overlapping. Any trade that improves at least one agent's welfare without decreasing the others' is a Pareto improvement.

[5] This exposition follows Farrell (1957). This discussion could be extended to revenue functions and profit functions by considering the output side simultaneously with inputs (Färe and Primont, 1995).

The environmental context of energy use in the economy requires us to revisit the form of the production possibilities frontier presented in Fig. 1a, since the economy produces some undesirable outputs jointly with the desirable ones. Following Färe et al. (1993) we consider a production possibilities frontier with jointly produced desirable and undesirable outputs. "Good" outputs typically have a value, or price, in the market, while "bads" frequently are not priced by the market. If we take account of the "bads" associated with economic production, then the production possibilities frontier could be represented as in Fig. 1c. This figure shows the production possibilities frontier with one aggregate good output, GDP, and one representative 'bad' output, carbon dioxide. Note that over some range of the production possibilities frontier the relationship between GDP and carbon is upward sloping (or equivalently, "downward sloping to the left"). This reflects the observation that with a given technology and a fixed set of input resources, lowering carbon emissions requires giving up some desirable output, in this case GDP. This is the same as the opportunity cost imposed by the resource constraint in Fig. 1a, except that the joint production assumption of GDP and carbon implies that the production possibilities frontier is upward sloping in some range. Theory also requires that GDP be bounded for a given set of inputs, so the production possibilities frontier has a maximum for GDP. If production is not efficient, then both "good" and "bad" outputs may be changed, without incurring any opportunity cost, by eliminating the technical inefficiencies. If "bads" had no effect on the welfare of society, then allocative efficiency would be achieved at point M.

It should be emphasized that our discussion here focuses on the narrow question of technical efficiency, and implicitly adopts the convexity assumption common to most CGE models. However, there is no theoretical reason that the maximum GDP determines a unique level of carbon as drawn. The production possibilities frontier could have a 'flat spot' or nonconvexities resulting potentially in multiple carbon values.[6] In such a case, there would not necessarily be a unique solution to the problem of optimal allocation that could be determined by the standard cost-benefit methodology. Such phenomena are ruled out by assumption, however, in most CGE models applied to energy or carbon policy. In addition, for the purpose of this exposition, the production possibilities frontier to the right of point M is not shown, since we have no specific expectations as to its shape. Theory does require that it be bounded, however.

[6] One potential source of non-convexity is increasing returns in production or consumption; this and related issues, and their implications for climate policy, are discussed in Peters et al. (1999).

This background allows for a straightforward interpretation of the CEF and other "bottom-up" studies: the point of these studies is that the economy is not on its aggregate production possibilities frontier. In particular, the specific inefficiencies that arise on the input side, with respect to energy, give rise to corresponding inefficiencies on the output side, with respect to GDP and carbon. The essential finding of the "bottom-up" approach is that there are large-scale organizational and/or market failures, in addition to potentially substantial transactions costs, that prevent consumers and firms from obtaining many energy services at least cost. ("Energy services" are the combination of energy with other inputs, usually capital, to produce the desired service. For example, in lighting the energy is electricity while the energy service is illumination, requiring both energy and capital.) The essential conclusion is that this general problem can be overcome, to a considerable extent, through policies that help correct the market failures, induce productivity-enhancing organizational change, and reduce the transactions cost barriers to the diffusion of energy-efficient technologies.

In other words, the CEF and similar studies provide empirical evidence that a Pareto improvement is available through intervening in markets for energy services and by adopting various policy measures. Hence, intersectoral shifts and adjustments in factor markets that might take place as a result of the policies in question *are accompanied by a net gain in economic efficiency*. This gain accrues as a result of investments having rates of return that are equal to or greater than the returns available on other investments of comparable risk.

It is important to point out that, as a corollary, the CEF and similar studies do *not* claim, as is often argued by their detractors, that energy is "special" with regard to evidence of inefficiency and departure from the production possibilities frontier. Other departures from economic optimality may also exist and may or may not be related to energy inefficiencies. The focus of the CEF is simply on those energy and carbon dioxide-related inefficiencies. Moreover, the interpretative framework we are proposing here makes it clear that energy efficiency need not be the same as economic efficiency. Energy efficiency is the optimization of sub-production functions—for example, for lighting, heating, or refrigeration—of an energy aggregate or energy service as above, costs are understood to be as fully specified as possible, i.e. to include transaction costs, etc.[7] Note that *only when an energy service function is separable* from the overall production function is such sub-optimization possible.[8] The optimization of the overall production function requires the optimization of the underlying function, but not vice-versa. When energy (service) is not separable, then energy efficiency requires the overall cost optimization of the production function, i.e. energy is allocated optimally among all resources, and energy efficiency is defined to be equivalent to economic efficiency in this case.[9] From this perspective, we see that energy efficiency is a necessary but not sufficient condition for economic efficiency, or optimality. Energy efficiency is not the minimization of energy costs without regard to other inputs. It is best thought of as the minimization of energy service costs, with regard to cost of other inputs to energy services, to the extent that energy services are separable.

This way of framing the "bottom-up" approach rests solidly on more than 40 years of theoretical and empirical study by economists and operations researchers of the measurement of economic and technical efficiency. The basic notion of technical efficiency dates back to Koopmans (1951), Debreu (1951), and Farrell (1957). The ideas found in Farrell's influential paper are chronicled in Førsund (1999), and a recent bibliography by Cooper et al. (1999) contains over 1500 references.[10] Although this literature goes well beyond the 'bottom-up' engineering estimates of energy saving technology, the connection between energy efficiency and production efficiency has been recognized in the energy economics literature (Huntington, 1994). Empirical connections between energy and economic efficiency can be made in studies of the technical efficiency of energy-intensive production activities. Boyd and McClelland (1999), Boyd and Pang (2000), and Boyd et al. (1993, 1994, 1998) focus on technical efficiency measurement in energy intensive industries, including steel, cement, glass, and paper. These papers are not the only evidence of production inefficiency in general or efficiency of energy intensive production specifically; deep theoretical

[7] When transaction costs are not observed, this may be a reason why a firm appears to be inside the production frontier. (It should be noted, however, that attributing all apparent inefficiencies to ubiquitous but unobservable "transactions costs" is tautological, and amounts to non-scientific hand-waving.) Removing or reducing the transactions costs allows the firm to move toward the frontier. When transactions costs are explicit, removing or reducing the transactions costs changes the price line, changing the optimal input allocation. Policies in the CEF are oriented toward, among other things, reducing the transaction costs via public action when the cost of doing so is less than the sum of the private costs.

[8] See Blackorby et al. (1978) for a discussion of separability and its implication for economic models. Blundell and Robin (2000) provides a theoretical extension of separability that is particularly useful for energy.

[9] Many technologies examined in the CEF are reasonably viewed as being separable, which allows for the definition of energy services.

[10] This bibliography focuses on a specific branch of this literature that uses a non-parametric linear programming approach called Data Envelopment Analysis (Charnes et al., 1978). There is also a substantial empirical and theoretical literature using statistical and non-statistical parametric methods (see Førsund, 1999 for a discussion of the methodologies; see Green, 1993 for a detailed treatment of statistical parametric methods).

reasons for the pervasiveness of inefficiencies are to be found in the literature on free-riding and principal/agent problems in firms and other groups (Olson, 1971; DeCanio, 1993 and the references cited therein), and in the arguments that economic agents and organizations exhibit various forms of bounded rationality (Simon, 1997; Conlisk, 1996; DeCanio, 1999).

Returning to our main theme, the framework we have described suggests how to incorporate both the estimates of the economic efficiency gain from "bottom-up" policies and the trade-off and corresponding economic adjustments that occur as a result of placing a price on carbon emissions. The way to combine results from CGE models with the findings of the technology-based studies such as the CEF is to account separately for movements *towards* the production possibilities frontier that are attributable to policy-induced efficiency improvements and movements *along* the production possibilities frontier that are due to the trade-offs arising from the opportunity cost imposed by resource constraints. These effects can be estimated by examining the models which focus on those effects separately. Movements toward the production possibilities frontier can best be derived from the calculations in the bottom-up methodology. Movements along the production possibilities frontier are implicitly represented by the CGE models and can be inferred from the published studies belonging to that literature. With estimates of these two effects in hand, a comparison of their magnitudes can be made.

Of course, a single model that reflects both kinds of effects would be preferred. However, this would require a CGE framework that included a detailed technology representation for the various energy consuming sectors or a parametric representation of utility and production/cost functions estimated using methods that account for efficiency.[11] Such a model does not yet exist in mature form, although some CGE models have taken steps toward such integration via greater representation of technology detail.[12]

It might be argued that CGE models, the parameters of which are either estimated from or calibrated to historical data, already take account, albeit implicitly, of many of the technologies and behavior that are the focus of the bottom-up studies like the CEF. This raises the question of whether our framework, taking estimates from two different veins in the literature, may result in some overlap or double counting. The extent of double counting depends on whether the estimates for the underlying price responsiveness in the CGE models are biased due to the presence of inefficiency and by how much. If the price response in the CGE models includes some shifts in the level of technical efficiency instead of purely a frontier price response, then the results from the two methods cannot be added together without an additional adjustment. However, Green (1993) shows that there is no way to tell in which direction an elasticity may be biased when one fails to account for inefficiency in the underlying data.[13] For this reason, the simple production possibilities frontier is proposed as a reasonable framework to compare the magnitude of the two effects.

3. Estimates of potential general equilibrium effects

In order to obtain estimates of the different types of effects of the CEF policies on GDP as suggested by the production possibilities frontier framework, we carry out the following series of calculations:

(1) Estimate the size of the GDP enhancement resulting from the policies of the CEF's Moderate scenario. This scenario does not include any carbon charge, so that by the assumptions discussed above its economic effects are due entirely to its removal of market and organizational barriers to profitable investments and its lowering of transactions costs throughout the economy. These improvements in economic performance represent a pure gain to the economy, a gain that is possible because the economy is initially inside its production possibilities frontier.

(2) After the Moderate scenario's GDP increment has been realized, introduce the \$50/ton carbon charge that is part of the Advanced scenario, but include none of the other policies of the Advanced scenario. The literature on CGE models reports the results of various runs of those models with alternative carbon charges. Using these estimates, it is possible to calculate a predicted drop in GDP resulting from the carbon charge alone. The difference between the GDP gain of the Moderate scenario and this estimated GDP loss from the carbon charge when added to the Moderate case is a *lower bound* for the GDP gain that could be achieved from the Advanced scenario, because none of the other

[11] See Green (1993) for a review of these statistical techniques.

[12] For example, the MARKAL-MACRO model is one that embeds a well-known technology optimization model into an aggregate economic model. The All Modular Industry Growth Assessment (AMIGA) model is designed to incorporate both types of effects, but has a limited history in the peer reviewed literature to date (see Hanson and Laitner, 2000; Hanson et al., 2000).

[13] In practice, the bias may not exist or may be negligible. For example, Boyd and Pang (2000) find that estimates of economic (technical) efficiency are significant in explaining the variation in energy output ratios. However, the price coefficient when efficiency is added to the regression model is not significantly different from the estimate without the efficiency variable. Their approach is *ad hoc* and does not address the issues raised by Green (1993).

productivity-enhancing policies of the Advanced scenario is included in the calculation.

The simulations of a \$50/ton carbon charge that we apply assume what is known as "lump-sum recycling" of the revenue that would accrue to the government from such a charge under an auctioning system. This means that the revenues are returned to consumers or firms in such a way as to induce only an income effect and no substitution among goods and services. As we note in the Introduction, this is a conservative assumption in that it rules out possible gains in economic efficiency from using these revenues to reduce other tax distortions. We discuss this point more completely in Section 4.

(3) The potential GDP gain from the Advanced scenario (measured as the Net Direct Savings[14] under that scenario) amounts to an upper bound on the GDP gain that could result from the Advanced scenario. The Advanced scenario includes technological change policies that shift the production possibilities frontier beyond what it is under the Moderate scenario, as well as technological change induced by the \$50/ton carbon charge. However, the Net Direct Savings estimated by the CEF for the Advanced scenario does not account for a possible shift along the production possibilities frontier brought about by the carbon charge. (It is a premise of both the Moderate and Advanced scenarios that the levels of energy services provided under the scenarios remain generally the same as in the baseline case.) Hence, the Net Direct Savings calculated under the Advanced scenario is an *upper bound* for the GDP augmentation effect of the Advanced scenario. Subtracting the same GDP loss associated with the \$50/ton carbon charge as in step (2) from the Advanced scenario's Net Direct Savings gives an estimate of the GDP change under the Advanced scenario that takes account of the substitution effect induced by the carbon charge.

This methodology is illustrated in Fig. 2. This figure displays the different possibilities in schematic form. The economy initially is at point I, inside the production possibilities frontier that can be reached by the Moderate scenario's policies. Implementation of the Moderate scenario moves the economy to point M, with a corresponding increase in GDP from GDP_0 to GDP_1. The line depicting "current relative prices" is tangent to the production possibilities frontier at M, and represents the current situation with no carbon charge. A \$50/ton carbon charge shifts the relative price line and makes it upward sloping. The tangency of the new price line to the production possibilities frontier is at point B, which represents the best the economy can do under the Moderate scenario but with a \$50/ton carbon charge. GDP falls from GDP_1 to GDP_2, reflecting the tradeoff between carbon emissions and GDP that comes about when there is a charge for carbon emissions.[15] The points A_1 and A_2 represent the two possible interpretations of the Advanced scenario. At A_1 there is no substitution of carbon reductions for GDP caused by the carbon charge, while at A_2 this substitution is taken into account.[16] The Net Direct Savings of the Advanced scenario is represented by the quantity GDP_3–GDP_0; this quantity represents the upper bound on the GDP effect of the Advanced scenario. The difference GDP_4–GDP_0 gives the intermediate estimate of the GDP gain of the Advanced scenario when substitution is taken into account.

It remains to estimate the magnitude of the substitution effect resulting from implementation of the \$50/ton carbon charge. Stanford University's Energy Modeling Forum recently compared results from simulations by the leading energy/economic models of alternative scenarios for achieving the carbon emissions targets of the Kyoto Protocol (Weyant and Hill, 1999). The scenarios varied according to how much (and among which countries) international trading was allowed to take place. Four trading scenarios were run: (1) no trading of international emissions rights; (2) full Annex I (or Annex B)[17] trading of emissions rights; (3) the "double bubble", which considers separate EU and rest of Annex I trading blocs; and (4) full global trading of emissions rights. The outputs of the model runs under these different scenarios (noting that some models were not capable of running every scenario) included estimates of the implicit "carbon tax" or marginal cost of carbon emissions reductions associated with the particular scenario and model, as well as the corresponding estimates of GDP reductions. These estimates are displayed in Table 1.

As Table 1 shows, EMF-16 reports "a wide range of estimates of the cost of the Kyoto Protocol. This range of estimates reflects differing assumptions about how the Protocol will get implemented and differences in the

[14] Net Direct Savings is defined as "[t]he difference between the energy bill savings and the direct costs (annualized incremental technology investment costs plus the program implementation and administration costs)" (CEF, 2000).

[15] Note that although measured GDP falls as the economy moves from M to B, economic *welfare* can improve because society values the additional environmental services that are obtained at point B. See DeCanio (1997) for a full discussion.

[16] A recent study of productivity in OECD countries supports the notion that countries are inside their GDP-CO_2 production frontier and that this frontier has been shifting as shown during the decade of the eighties; see Boyd et al. (1998).

[17] The Annex I (of the 1992 Framework Convention on Climate Change) countries include the US, OECD-Europe, Japan, Canada/Australia/New Zealand (CANZ), and the EEFSU (East Europe and Former Soviet Union) countries. The Annex B (of the Kyoto Protocol) list varies slightly from the Annex I list (Weyant and Hill, 1999).

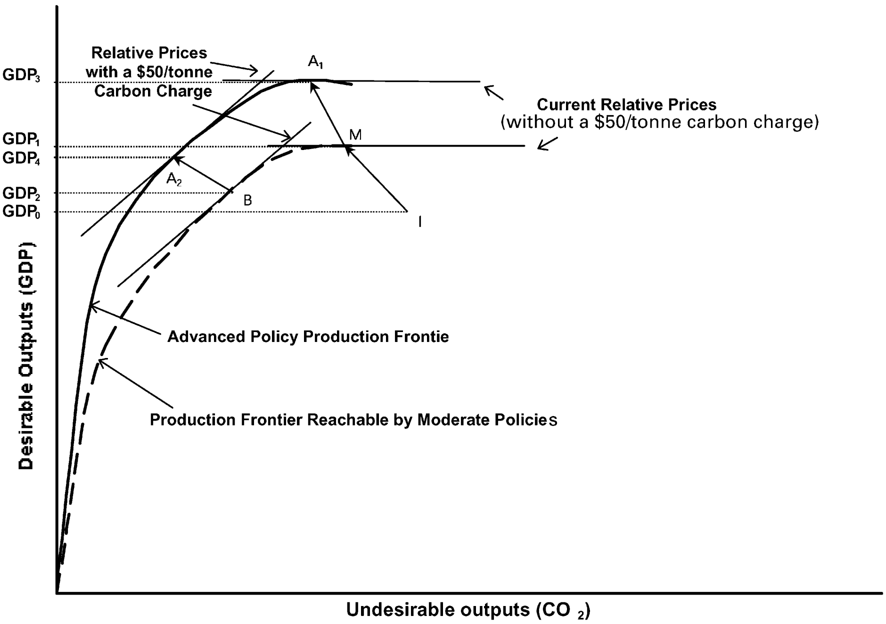

Fig. 2. CEF scenarios and substitution effects.

Table 1
US GDP effects and implicit carbon charges, various emissions trading scenarios[a]

Model	Implicit carbon charge, 1990$				GDP loss in 2010, billions of 1990$			
	No trading	Annex 1 trading	Double bubble	Global trading	No trading	Annex 1 trading	Double bubble	Global trading
ABARE-GTEM	$322	106	100	23	$182	75	71	19
MS-MRT	236	77	N/A	27	181	88	N/A	28
CETA	168	46	N/A	26	170	59	N/A	38
MERGE3	265	135	N/A	86	90	43	N/A	17
RICE	132	62	N/A	18	84	61	N/A	22
AIM	153	65	45	38	38	26	19	17
G-Cubed	76	53	28	20	35	20	−4	5

[a] *Sources*: EMF-16; Weyant and Hill (1999), Weyant (1999). The Oxford model was not included because it is not a CGE model. G-Cubed is a hybrid general equilibrium/macro-econometric model because it does consider some unemployment and financial effects. Some other EMF-16 model results are not listed because they did not calculate GDP effects.

structures of the models used to make the cost projections .... The principle model differences that impact the magnitude of the cost estimates are the level of baseline emissions during the first budget period (2008–2012), the value of the substitution and demand elasticities embedded in the models, and the rate at which it is assumed that the stock of energy using equipment can be adjusted over time'' (Weyant and Hill, 1999, p. xliii).

To estimate the GDP loss associated with a $50/ton carbon charge, we calculated a ''GDP response curve'' for each model indicating the expected response of GDP to various carbon trading values. We determined this curve by a quadratic extrapolation using the Annex I trading and global trading scenarios as reported by EMF-16. (These are the scenarios with carbon trading values that bracket or are close to the $50/ton level.) For each model, the origin and the points corresponding to the implicit carbon charges and GDP losses determine a unique quadratic response curve.[18] The curves must pass through the origin because, by construction, CGE models show no deviation of GDP from the baseline if no carbon tax is imposed. The figures from Table 1 were converted to 1997$ using the GDP deflator (Council of Economic Advisers, 1999, Table B-3). The results, with

[18] The unique quadratic passing through the three points (0,0), (x_1, y_1), and (x_2, y_2) is given by the equation

$$y = \left[\frac{y_1 x_2 - y_2 x_1}{x_1^2 x_2 - x_2^2 x_1}\right] x^2 + \left[\frac{x_1^2 y_2 - x_2^2 y_1}{x_1^2 x_2 - x_2^2 x_1}\right] x$$

the mean and median of the estimates, are displayed in Table 2.

To complete the calculation, these estimated GDP losses can be compared to the GDP *gain* from the Moderate and Advanced scenarios as calculated by the CEF. The net result is that the gain in GDP brought about by the efficiency-improving policies of the Moderate scenario offsets or is roughly equal to the median loss of GDP caused by the substitution induced by the \$50/ton carbon charge. The combined impact of the Advanced scenario and the substitution effect is a slight gain in GDP if either the mean or median estimate of the substitution effect is used. The comparisons are shown in Table 3.

The Advanced scenario projects Net Direct Savings in 2010 of \$48 billion. Thus, the net GDP change after accounting for macroeconomic substitution effects lies between −\$26 billion (the lowest of the estimates of GDP_2–GDP_0) and \$48 billion (the estimate of the GDP gain from the Advanced scenario without any GDP substitution effect). If the substitution effect is added to the GDP gain from the Advanced scenario, the change in GDP ranges from −\$18 billion to \$ 44 billion. The mean and median estimates of the CEF Advanced scenario + Substitution Effect are \$11 billion and \$9 billion, respectively. The conclusion for 2010 is that the GDP increase that arises from efficiency improvements, as estimated by the CEF analyses, is similar in magnitude to (or perhaps slightly larger than) the substitution effect from a \$50/tonC carbon trading permit.

Table 2
Estimated 2010 GDP loss (1997\$) associated with \$50/ton carbon charge, quadratic GDP response curve, EMF-16 data[a]

Model	Estimated GDP loss (billions of 1997\$)
ABARE-GTEM	39
MS-MRT	54
CETA	66
MERGE3	4
RICE	55
AIM	22
G-Cubed	16
Mean	37
Median	39

[a] *Source*: EMF-16; see text.

4. The importance of fiscal policy: "recycling" carbon charge revenues

The discussion above encompasses only the substitution effects of carbon charges. As noted in the Introduction, however, a system in which tradable carbon permits were auctioned to emitters or to fossil fuel producers would result in a potentially large amount of revenue flowing to the government. The alternative would be to "grandfather" the permits, i.e., allocate them without charge to emitters or fuel producers. As we now describe, the use of the revenue in the case of auctioning would have potentially significant implications for the macroeconomic impacts of carbon charges.[19]

The starting point for fiscal policy in the neoclassical framework is that taxes of any sort introduce "distortions" into the economy by changing the behavior of consumers and firms (Auerbach, 1985).[20] Distortionary taxes on income or investment entail some (gross) economic losses even if there is a positive net effect once these taxes are used to provide, say, public goods and services.

The fact that a carbon permit system would be introduced in the context of our pre-existing system of taxes suggests the possibility of substituting carbon revenue for the revenue from income or investment taxes. The standard baseline for measuring the efficiency impacts of such policies is "lump-sum" return of the revenues to consumers and/or firms. A lump-sum return of the tax revenues means that the money is given back in such a way as to induce a pure income gain without causing substitution among commodities or between labor and "leisure". This method of revenue recycling leaves existing tax distortions unchanged. This is the assumption made in the simulations we applied in Section 3, and is implicit in our theoretical discussion of Section 2.

By contrast, such existing distortions could be reduced by returning carbon revenue to consumers and firms by reducing *marginal* tax rates on income or investment or both. The fundamental finding in this case is that *this form of revenue recycling lowers the economic costs of carbon charges relative to a policy of lump-sum return*. In essence, environmental policy is made to serve fiscal policy by reducing the economic efficiency losses from existing tax distortions.

A stronger result has been hypothesized and studied extensively: whether using carbon revenues to reduce existing tax distortions might actually lower the overall cost of carbon charges to zero (or make this cost negative). The most recent research shows that this "strong double dividend" hypothesis is validated when sufficient detail on pre-existing tax distortions is taken into account, and when tax-favored consumption goods are incorporated (Parry and Bento, 2000). In addition, it has been demonstrated that auctioning permits and using the revenue appropriately produces significant efficiency gains over systems in which permits are grandfathered (Parry et al., 1999).

[19] The topic of this section is discussed at length in Goulder (1996).

[20] Despite the terminology, in some cases "distortionary" taxes can in fact improve economic welfare directly, e.g., emissions taxes that reduce environmental damages.

Table 3
Estimated 2010 GDP changes from different policy combinations, billions of 1997$, various models, CEF and EMF-16 data[a]

	EMF-16 model							Mean	Median
	ABARE-GTEM	MS-MRT	CETA	MERGE3	RICE	AIM	G-CUBED		
GDP_1–GDP_0 (CEF moderate scenario)	$40	40	40	40	40	40	40	40	40
GDP_2–GDP_1 (GDP substitution effect)	−39	−54	−66	−4	−55	−22	−16	−37	−39
GDP_2–GDP_0 (CEF Moderate + Substitution)	1	−14	−26	36	−15	18	24	3	1
GDP_3–GDP_0 (CEF Advanced scenario)	48	48	48	48	48	48	48	48	48
GDP_4–GDP_0 (CEF Advanced + Substitution)	9	−6	−18	44	−7	26	32	11	9

[a] *Source*: See text, Fig. 2.

A number of studies using CGE models have demonstrated the importance of revenue recycling in determining the economic costs of carbon charges. Goulder (1995) studied the effects of a carbon tax of $25/ton, offset by reductions in period-by-period marginal tax rates (and compared to lump-sum reductions). The result of this revenue recycling option relative to lump-sum rebates was significant: in terms of GDP, losses from the carbon tax were reduced by 40–55% in the long-run, with the largest offset obtained through cuts in personal taxes. Jorgenson and Wilcoxen (1993) studied the effects on real GNP in year 2020 of a carbon tax of $15/ton imposed in 1990, rising by 5% annually. Relative to lump-sum rebating, cuts in a labor tax reduced GNP loss by 60%—from 1.7% to 0.69% reduction from the baseline GNP forecast. In the case of recycling through reducing taxes on capital, 2020 GNP was actually increased *above* the baseline, by 1.1%—a "strong" double dividend outcome.

Such results reinforce the conservative character of the estimates we presented in Section 3. Using the $50/ton carbon charge revenues to reduce marginal tax rates in a CGE framework would lower the estimates of the macroeconomic substitution effect that we obtained. In the following section, we will show that revenue recycling assumptions also have significant implications for the analysis of shorter-run effects.

5. A note on transition impacts

A key characteristic of CGE models is the assumption of complete equilibrium—supply equaling demand—in all markets. In particular, while employment in specific sectors can rise or fall, there is no involuntary employment anywhere in the economy. In addition, these models do not contain a representation of money; instead, consumers and firms make choices on the basis of real relative prices. The CGE models are generally viewed as representing underlying, long-run features of the economy. When applied to analyzing a policy such as a system of carbon emissions permits, they similarly describe the state of the economy after it has fully adjusted to the intervention.

By contrast, Keynesian models such as that of DRI allow for involuntary unemployment, and represent the money supply explicitly, thereby also permitting the modeling of monetary policy. These models are best suited to analyzing the transition—up to five years—response of the economy to policy changes or economic "shocks". For this reason, it has been suggested that Keynesian models are more appropriate than CGE models for estimating the "true" GDP impacts that would result from carbon charges of the type assumed in the CEF. To address this claim, we now summarize several results from applying the DRI model to estimate GDP impacts of the CEF scenarios (complete details are provided in Section 5 of Appendix E-4 to the CEF).

The DRI model contains several measures of overall economic performance. The "potential GDP" is the economy's maximum potential output, and thus corresponds to GDP as it is represented in CGE models. In addition, the model tracks "macroeconomic adjustment costs", which in the case of carbon charges are transition frictions caused by the economy's reacting to higher energy prices.

The DRI model has been applied to several analyses of the effects of introducing carbon charges into the US economy. The most extensive were undertaken by the Energy Information Administration (EIA) of the US Department of Energy in studies of the potential effects of US compliance with the Kyoto Protocol (EIA, 1998, 1999a). The EIA analyzed several scenarios corresponding to different US emissions reduction targets to be achieved on average between 2008 and 2012, phased in beginning either in 2000 (the "Early Start" case) or in 2005. These scenarios were analyzed using the DRI macroeconomic model in conjunction with the National Energy Modeling System (NEMS).

To compare the EIA's results to our analysis based on CGE models in Section 3, above, we undertook a series of calculations based on these scenarios to estimate the effect of including EIA's estimated transitional costs in our previous estimates. The Early Start scenario corresponds most closely to the CEF Advanced scenario, both in terms of timing and because it assumed lump-sum recycling of carbon revenues. We found that the Early Start case including transitional costs resulted in an overall GDP loss from a \$50/ton carbon charge of \$39 billion (US \$1997), precisely the median of the range predicted by the CGE models.

Although the timing of EIA's 2005 scenario differs from that of the CEF, it is of interest because it includes additional detail on revenue recycling options. In this scenario, the EIA considered both lump-sum recycling (in the form of a personal income tax rebate), and recycling by means of a reduction in the marginal Social Security tax rate applied to both employers and employees (Earley, 2000 pers. comm.). Again using EIA's results to add approximate transitional costs to estimated losses of potential GDP, we found that estimated total short-run GDP losses were \$74 billion in the "lump-sum" case and \$47 billion in the marginal rate reduction case (both in 1997 dollars). The difference between the two cases in the EIA's own simulations was comparable (\$97 billion vs. \$62 billion).

The differences between the two revenue recycling cases, both in the EIA's simulations and in our corresponding approximations, indicate that the disposition of carbon charge revenues is as important for transition costs as it is for the long-run costs analyzed by the CGE models. A more dramatic illustration of this importance is given by an application of the DRI model in a study of tradable emissions systems for the US Environmental Protection Agency (Probyn and Goetz, 1996). This study analyzed the effects of approximately stabilizing US greenhouse gas emissions in the year 2010 at 1990 levels using various permit systems. (The target allowed carbon emissions to rise 60 million tons above their 1990 levels by 2010.) In each scenario, the permit system is introduced in 2000.

Among the permit systems studied was a scenario in which 40% of revenues from permit auctions were returned to consumers in the form of lump-sum rebates, and the remaining 60% recycled to corporations by lowering the statutory corporate income tax rate. The effect of this variation is considerable: the estimated actual GDP is less than 0.5% below the baseline throughout the adjustment period, and rises (and remains) *above* the baseline eight years after the system is put in place. The potential GDP (the variable corresponding to that measured by the CGE models) *rises and remains above baseline from the time the permit system is introduced*. This result shows that, even in the transition period, potential GDP losses can be avoided altogether—and indeed, potential GDP gains can result—when revenue recycling is used to stimulate investment. This result is comparable to that of Jorgenson and Wilcoxen as described above in Section 4.

To completely analyze the transitional macroeconomic impacts resulting from the carbon charge in the CEF Advanced scenario would require a full simulation using a model such as DRI's. The findings we have reported here, however, suggest that these impacts would be largely, if not completely, dependent on the manner in which the carbon charge revenues were returned to the economy.

Even in the absence of judicious use of revenue recycling, there are reasons to believe that the transitional costs associated with carbon charges would not be as severe as is sometimes thought. When the economy experiences unanticipated and unannounced changes, or shocks, the short-run disequilibrium in factor markets can be severe. Such was the case in the 1970s when oil prices rose dramatically and without warning. When there are large and unexpected shifts in the economic landscape there is no time for planning and market adjustments. Consequently, existing capital may be rendered less valuable and resources temporarily underutilized until the economy recovers. However, the technology-based policies outlined in the CEF would be neither unanticipated nor unannounced. Instead, they would be phased-in programs, designed to work in conjunction with normal capital stock turnover to minimize the disruption in investment planning and capital purchases. While there would be inevitable shifts in the output of different industries, the prior announcement and phase-in would allow for a gradual transfer of labor and other productive resources. This might not eliminate the short-run disequilibrium, but would substantially reduce it.

6. Summary and concluding remarks

This paper has presented a perspective by which the CEF and similar studies may be placed in a macroeconomic context. In concluding, it is worth pointing out that, as a practical matter, the magnitude of the potential economy-wide energy-efficiency investment contemplated in CEF is small relative to aggregate total investment. The annual total cost (Annualized Incremental Investment Costs + Incremental RD&D Costs + Program Costs) of the Moderate Scenario is less than \$20 billion in 2010 and approximately \$40 billion in 2020 (in 1997\$). The annual total cost of the Advanced Scenario is approximately \$40 billion in 2010 and approximately \$80 billion in 2020. By comparison, the AEO99 reference case projects Real Investment at annual rates of \$2011 billion in 2010 and \$2508 billion in 2020 in 1997 dollars.[21] Thus, the CEF scenario costs

[21] The 1992 dollars of the AEO99 reference case are converted to 1997 dollars using the 1997 chain-type price index for Fixed Gross Private Domestic Investment (AEO99, Table 20; Council of Economic Advisers, 1999, Table B-7 (EIA, 1999b)).

range between 1% (2010, Moderate Scenario) and 3% (2020, Advanced Scenario) of projected total Real Investment. The ratios indicate that the investments induced by the CEF policies are quite small relative to total investment. Whatever the ultimate analytical and quantitative estimates of the macroeconomic effects of energy technology policies, these magnitudes should be kept in mind.

We identified three principal macroeconomic effects that operate under the types of greenhouse gas control policies outlined in the CEF. These three effects may loosely be called (a) the "efficiency" effect, which moves the economy toward its production frontier from the interior; (b) the "substitution" effect, which moves the economy along the frontier, and (c) the "technology shift" effect, which moves the frontier outward. We used the aggregate results of the CEF study with a simple synthesis of scenario outputs from EMF-16 to assist in estimating the magnitude of these three types of macroeconomic effects, all of which are relevant to the policy discussion. While this paper does not represent a complete analysis of greenhouse gas reduction policies, it serves to estimate the general magnitude of these important effects. While a model that integrates the concepts of technical efficiency and price (or opportunity cost) would be preferred, we have derived estimates of these different effects from models in the open literature that focus on each. We find that the competing effects are of similar magnitude. When the estimates are added together the net effect tends to be a small positive impact. Since theory does not provide guidance as to the size or direction of the possible overlap between the estimates, we believe that this approach provides a reasonable indicator that the magnitude of the net effect is indeed small and probably positive. Further development of an integrated model and research on the nature of the "overlap biases" of the price and technical efficiency effects would be desirable to improve upon these estimates.

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